The impact of solid cooking fuels on the health of rural South African households

by

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TTHJUL001

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Abstract

Indoor Air Pollution (IAP) from the combustion of solid cooking fuels has been proven to adversely affect the health of household residents. Those most affected by IAP are the poorest and most vulnerable members of society, specifically poor women and children residing in rural households. This study evaluates the impact of using solid cooking fuels on various health outcomes of residents in rural South Africa, using the nationally representative General Household Survey 2018. Propensity Score Matching Methods are used to address the confounding of variables associated with the use of solid cooking fuels and health outcomes. We find that the use of solid fuels significantly increases the risk of suffering from Acute Respiratory Illnesses (ARI's) as well as increasing the risk of residents reporting a poor health status. Our analysis goes on to evaluate separate gender and age groups and find some evidence that women and the elderly may suffer relatively more adverse health outcomes from the use of solid cooking fuels. Our results suggest that IAP from the combustion of solid fuels poses a threat to health of South Africans residing in rural households. Hence policy should focus on providing access to clean sources of energy for cooking in rural areas.

1 Introduction

The World Health Organisation (WHO, 2016) estimates that globally more than 3 billion people rely on solid fuels such as wood, charcoal and dung for cooking. The use of solid fuels for cooking and heating is the predominant source of indoor air pollution (IAP) in the developing world. Exposure to the by-products of the inefficient combustion of these fuels has been found to be related to numerous health problems (Rahut et al., 2017; Shezi and Wright, 2018; Qiu et al., 2019). The burning of solid fuels for such domestic purposes can produce high levels of toxic pollutants such as particulate matter (PM) and carbon monoxide. Exposure to particulate matter significantly increases the risk of acute respiratory tract infections (ARI's), which is the leading cause of death in children under the age of five in South Africa (StatsSA, 2016). WHO (2016) estimates that ARI's kill almost a million children each year and account for 15% of fatalities among children under the age of five. IAP that arises from the use of solid cooking fuels is considered the second most significant cause of disease after contaminated water-borne diseases around the world (Duflo et al., 2008). Those profoundly affected by IAP are the poorest and most vulnerable members of society; women and children residing in poor rural households are often exposed to significant levels of pollutants for several hours daily (WHO, 2016).

According to the Vegter (2016), approximately one third of households in South Africa burn solid fuels for cooking and heating. Therefore, a large proportion of the South African population is exposed to IAP. Like many other developing countries, South Africa experiences both a high incidence of respiratory disease and widespread use of solid fuels (Shezi and Wright, 2018). It is estimated that IAP adversely affects the health of 20% of rural households in South Africa and accounts for the death of 14000 South African children each year (Vegter, 2016). There is a large body of literature which reports the adverse effects of indoor air pollution on human health in South Africa and other developing countries (Vegter, 2016; WHO, 2016). The number of empirical studies in South Africa that provide evidence of the severe impact of IAP and the use of solid cooking fuels on health outcomes, however, is limited (Barnes et al., 2009; Albers et al., 2015; Elf et al., 2017). There is a need for more quantitative research into the effect of IAP on human health within South Africa using larger studies and high-quality data. This will allow for studies to have more statistical power and more generalizable results.

Duflo et al. (2008) notes that there is very little evidence on the impact of IAP on economic outcomes. They argue that the negative health implications of IAP can significantly impact the general economic well-being of households by decreasing labour productivity and school attendance (Duflo et al., 2008). Multiple studies have noted the onerous task of wood collection and its effects on productivity. In low-income rural households the burden of gathering wood and in some cases coal to meet the household's energy needs is generally borne by women and children. Fuel collection therefore reduces the time women have available for contributing to other aspects of livelihood planning. Dinkelman (2011) found that access to electricity within rural areas was associated with a significant increase in female employment, since women were released from some of the drudgery associated with household energy management.

Few studies have been done in South Africa to investigate the link between IAP associated with the burning of solid fuels and health outcomes. More research is needed to analyse the effect of burning solid fuels on human health. This analysis aims to add to the literature on the impact of solid fuels on the health of South Africans. To our knowledge it is the first analysis done using a nationally representative survey to investigate this issue within South Africa. The rest of the paper is structured as follows; Section 2 reviews the literature on energy use patterns, IAP from domestic solid fuel burning, and the effects on health and productive outcomes. Section 3 provides the methodology of propensity score matching; matching strategies; variable selection; a description of the data; methodology for balancing propensity scores and some descriptive statistics. Section 4 presents the empirical results, with preliminary estimation of propensity score balance, aggregate results as well as results by gender and age subgroups. Section 5 presents a discussion of the findings. Finally, section 6 draws policy implications from our findings, highlights the limitations of the study and offers suggestions for further research.

2 Literature Review

2.1 Household Energy Use Patterns and Indoor Air Pollution

The energy ladder model, presented in figure 1, describes the relationship between a household's economic status and the quality of fuel they use for cooking and heating. In this theory household energy transitions are assumed to be a linear progression with three distinct phases (van der Kroon et al., 2013). As their economic status rises, households are assumed to move up the ladder from traditional fuels, such as wood and animal dung; to more convenient transitional fuels, such as paraffin and coal; and eventually to modern fuels, such as electricity and LPG. A major flaw in this model is that it assumes that a move up towards a cleaner energy source is simultaneously a move away from less efficient fuels. Research into household energy use patterns in South Africa shows that this is not the case, particularly in rural areas (Davis, 1998; Thom, 2000; Bohlman and Inglesi-Lotz, 2018). Davis (1998) found that household energy transitions in South Africa are characterised by a constant switching between different fuel combinations. Several studies have found that multiple fuel use and fuel switching behaviour is common among poor South Africans (Bohlman and Inglesi-Lotz, 2018; Sustainable Energy Africa (SEA), 2016). Despite the ladder's failure to capture the fuel switching behaviours of households, it does captures the strong relationship between income and household fuel choice. In developing countries, the continued reliance on inefficient fuels by the lower tiers of the energy ladder is most often the result of poverty. Modern fuels remain inaccessible to a large proportion of the population, either due to lack of access or affordability. The use of solid fuels is particularly prevalent in rural areas where access is less common and solid fuels are often freely available.

South African households have seen a significant change in their energy profiles in the last two and a half decades. The democratic transition from Apartheid

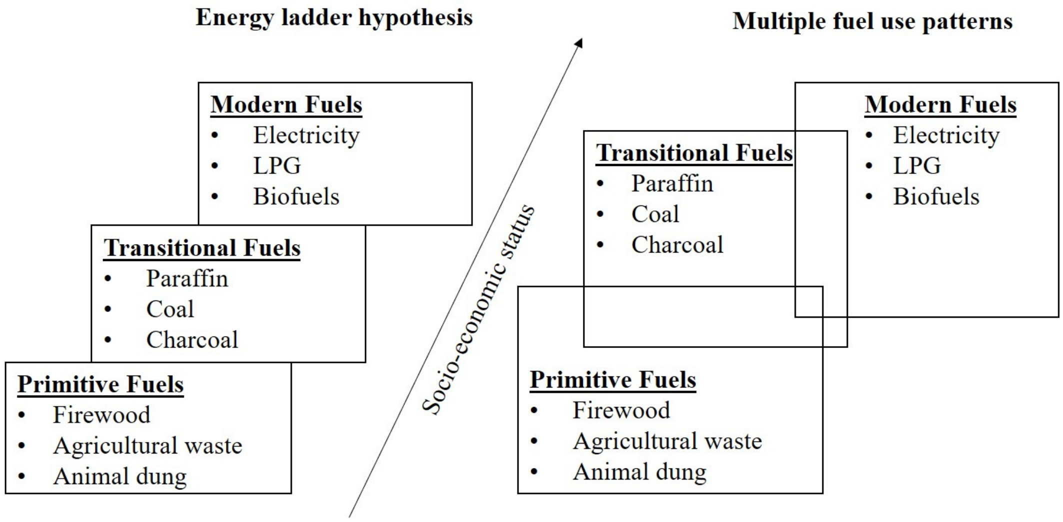

Figure 1: The energy transition process (Van der Kroon et al., 2013, pg2)

in the early 1990's brought with it a massive shift in the South African energy policy. Universal access to electricity was made a priority and the first democratically elected South African government, formed by The African National Congress (ANC), embarked on a rapid electrification program (Bohlman and Inglesi-Lotz, 2018). Since the ANC came into power in 1994, total electricity access increased from 60,8% to 86% in 2016; while rural access increased from 34% to 72% (Bohlman and Inglesi-Lotz, 2018). Davis (1998) found that access to electricity played a major role in assisting households in their transition towards the use of modern energy sources. In accordance with the energy ladder hypothesis, however, Davis (1998) found income to be the most important determinant of a domestic fuel choice. Rural South African households were found to move away from less efficient fuels as their income increased in both electrified and non-electrified areas. The fuel choice patterns of low-income electrified households were found to be very similar to those of non-electrified households. The continued reliance on inefficient solid fuels among electrified households is generally an indication of energy poverty (Sustainable Energy Africa (SEA), 2016). While the rapid electrification program in South Africa was ultimately successful, it failed to account for the fact that many rural households are unable to afford electricity costs beyond the free basic electricity subsidy[1] (Thom, 2000). The result is that household tend to turn to less efficient solid fuels to meet their energy needs. This problem is particularly prevalent in rural areas where fuel wood is often freely available.

According to Vegter (2016), one third of South Africans still use solid fuels as part of their energy mix. The use of solid fuels for cooking and heating indoors can expose a household to high levels of toxic pollutants. The combustion of solid fuels indoors has been found to be the most significant source of IAP in developing countries (WHO, 2016). Once ventilation is taken into account Vegter (2016)

[1]According to the free basic electricity policy and allocation of 50kWh per month should be provided to all households connected to the national electricity grid

estimates that approximately 20% of South African households are exposed to IAP. The negative health implications of high levels of pollution have been extensively researched. Pollution in South Africa is a huge cost to the national health sector. Scorgie (2012) finds that a IAP arising from the domestic use of solid fuels accounts for 68% of the overall health costs attributed to pollution. The overwhelming majority of households that rely on solid fuels are located in rural areas in South Africa, since these areas are characterised by poverty and a lack of services.

Data has shown that there are certain regions in South Africa, referred to as 'priority areas', where air pollution exceeds levels that regulators deem acceptable for human health (DEA, 2019). A lot of attention has been focused on South Africa's coal dependent industrial economy as the major cause of this pollution. However; it has become clear that the use of solid fuels to meet the energy needs of poor households is the most significant contributor to life threatening pollutants in South Africa (DEA, 2019). Emissions from domestic fuel burning have been found to be significantly worse than those from industrial pollution (DEA, 2019). The burning of solid fuels indoors produces similar toxins to coal fired power plants but at much higher concentrations. This is because the emissions from domestic solid fuels are released within the breathing zone of household residents. These individuals are therefore immediately exposed to the highest concentrations of pollutants which are extremely detrimental to their health. The combustion of solid fuels indoors releases pollutants such as carbon monoxide and particulate matter (PM) (Duflo et al., 2008). PM_{10} is the PM with a diameter of less than or equal to 10μm. These particulates are able to get through the nasal cavity and into the lungs of those who inhale it and are widely believed to pose the greatest health problems. WHO (2016) provides air quality guidelines that state that the levels of PM_{10} should not exceed a 24-hour average of $50\mu g/m^3$, while, the most recent version of the South African Air Quality Act (AQA) gives a guideline for a 24-hour average of $100\mu g/m^3$ DEA (2019).

Piketh et al. (2016) compared the ambient air quality to the indoor air quality of households residing in the Mpumalanga Highveld, an area with particularly high ambient air pollution levels. They found that the indoor air concentration on PM within households burning solid fuels was higher than the ambient concentrations outdoors by a factor of 7 during winter months. They found that the indoor air quality exceeded the WHO guideline of $50\mu g/m^3$ regularly in summer and in winter the ambient PM_{10} exceeded these guidelines for the entire two week period of measure. Adesina et al. (2020) compared the level of ambient air pollution of solid and non-solid fuel burning households in the Mpumalanga Highveld in South Africa. This study found that households that used solid fuels for cooking and heating in winter had average PM_{10} levels ranging between $60.9\mu g/m^3$ and $207.5\mu g/m^3$, while non-solid fuel burning households ranged between $15.3\mu g/m^3$ and $84.2\mu g/m^3$. In summer, when solid fuels were not often burnt indoors there was no significant difference between the particulate matter concentration between households. Both Piketh et al. (2016) and Adesina et al. (2020) conducted their studies on Reconstruction and Development Program (RDP) houses in low-income settlements, these are government subsidized houses. A study on the key issues related to RDP housing found that no proper ventilation systems were installed in 50 houses sampled in Gauteng. This suggesting that a large proportion of the almost 4 million households, which house 13.6 percent of the South African population, are not sufficiently ventilated to keep IAP levels below what would be considered dangerous to human health (Mashwama Nokulunga and Clinton, 2018). The measurements done on the pollution levels required by the new AQA legislation show that in many of the priority areas mostly in Mpumalanga the level of air pollution regularly exceeds what is considered acceptable. This presents a serious risk to human health. A change in the SA air quality regulations in 2005 resulted in the proper monitoring of pollution levels and evidence that domestic burning of solid fuels is one of the most significant factors contributing to high levels of PM in the priority areas around South Africa (DEA, 2019).

2.2 Indoor Air Pollution and Health Outcomes

The adverse health effects of pollution have been well documented. It was estimated that outdoor air pollution was responsible for 4.2 million deaths in 2016, while IAP from the use of solid fuels was responsible for 3.8 million deaths. WHO (2016) states that IAP is the "single most important environmental health risk factor world wide." Altieri and Keen (2019) estimate that in South Africa, high levels of PM in the air was responsible for more than 21000 deaths in 2012. DEA (2019) notes that domestic fuel burning is one of the most significant contributors to the PM concentration in South Africa, which suggests that a significant proportion of these deaths were the result of IAP. Norman et al. (2007) estimates that in 2000, indoor smoke from burning solid fuels was responsible for 2489 deaths in South Africa. They found that IAP was a significant risk factor for children under the age of 5 and ranked it as one of the leading causes of the loss of healthy life years among South Africans. Several studies in developing countries have found a strong correlation between the domestic use of solid fuels and health outcomes, especially with young children who are the most susceptible. Women and children are particularly vulnerable as they are typically the ones who spend the most time indoors cooking and tending to household chores. IAP from the combustion of solid fuels has been linked to several illnesses, such as acute lower respiratory illnesses (ALRI's), TB, pneumonia, bronchitis, cataracts, low birth weights, cardiovascular diseases and premature deaths. The number of South African studies that evaluate the health effects of IAP from burning solid fuels are few and limited, however, there is a growing body of literature which highlights cause for concern.

Acute respiratory infections (ARI's) includes viral and bacterial infections in the lungs and respiratory tract, the most sever and fatal being bacterial pneumonia (Bruce et al., 1998). Young children are more likely to contract ARI's from IAP as their lungs and immune system are not yet fully developed (Barnes et al., 2009). ARI's are one of the leading causes of death of children under the age of five in South Africa (StatsSA, 2016). WHO (2016) refers to ARI's as the "single biggest killer of children" under the age of five and estimates that more than half of the fatalities caused by pneumonia are the result of IAP from solid fuels. Child mortality as a result of ARI's is particularly prominent in Sub-Saharan Africa, which houses 4 percent of global deaths.

Most of the research on the effects of IAP in South Africa have investigated the link between IAP and respiratory illness in children. Albers et al. (2015) conducted a study on 124 children attending school in priority areas in Mpumalanga. They found that the prevalence of respiratory ill health among these school children was significantly elevated in households that used non-electrical fuels for cooking. Buthelezi et al. (2019) studied 245 households in a small township off the coast of Kwazulu-Natal and found a significant effect of using non-electrical fuels for cooking and heating on the respiratory health of residence. Shirinde et al. (2014) collected data on 346 school children from an informal settlement in Gauteng and found that domestic use of non-electrical fuels for cooking significantly increased the likelihood of wheezing among children in the sample.

Indoor smoke has been found to exacerbate symptoms of Tuberculosis (TB) and facilitate the transmission of this deadly and increasingly multi drug-resistant infection (Ranabhat and Jha, 2009). Various studies found an association between solid fuel use and TB (Rabbani et al., 2017; Elf et al., 2017). Elf et al. (2017) conducted a small study on 126 individuals in Klerkdorp, South Africa, and found that IAP from burning solid fuels was associated with a high prevalence of active TB being reported within the households. In a study of 234 children under the age of 14 in Durban Jafta et al. (2019) found that exposure to dirty cooking fuels increased the risk of childhood tuberculosis disease. The evidence of the relation between TB and IAP has, however; been somewhat contested. In a systematic review of 15 studies from developing countries, Lin et al. (2014) finds that, taking into account the quality of the studies, the evidence for the association between the use of solid cooking fuels and TB is low.

Chronic bronchitis, is an inflammation of the lining of the bronchial tubes that is typically the result of smoking (Bruce et al., 1998). In developing countries, the burning of solid fuels indoors has been found to increase the risk of bronchitis, particularly among older women. Asthma attacks have also been associated with IAP from solid fuels in developing countries (Smith, 2002). While the nature of the asthma and IAP interaction is not clear, the potential for trigger of attacks through direct airway irritation and as facilitating factor for other allergens seems substantial (Smith, 2002). Several studies have also looked into the relationship between self reported ill health and the use of solid fuels and have found a strong and significant correlation. Qiu et al. (2019) studied the effect of IAP on various health outcomes among elderly people in China. Using propensity score matching they found that the average treatment affect of solid fuel use was substantial and significant for self reported poor health.

2.3 Solid fuel use, productive outcomes and gender

The energy poverty nexus in South Africa has distinct gender characteristics. It is well documented that majority of the burden of domestic solid fuel use falls on women and young girls. Gender roles are such that women are generally the ones responsible for doing most of the fuel collection, cooking and household chores in poor South African households. Several studies have discussed the potential effect of a lack of access to modern energy on productive outcomes (Dinkelman, 2011; Burke and Dundas, 2015; Duflo et al., 2008; Liu et al., 2020). Most of this research has specifically focused on its effect on the productive outcomes of women. One of the biggest burdens of relying on solid fuels for cooking is the time burden. It is known that women spend a large proportion of their days collecting fuel wood, preventing them from being involved in other productive activities. Women living in rural areas in developing countries have been found to spend several hours collecting fuel daily (Clancy et al., 2003; Das et al., 2019; Rewald, 2017; Dovie et al., 2004). The amount of time spent collecting fuels varies significantly according to location and the availability of wood or coal, but the time estimates are uniformly significant (Rewald, 2017). Dovie et al. (2004) found that women in a rural village in South Africa spend more than two and a half hours a day collecting wood. The process of cooking with inefficient fuels has also been found to take significantly longer than when modern fuels and cooking technologies are not available (Rewald, 2017). The drudgery associated with the domestic use of solid fuels reduces the time available for women to contribute towards productive outcomes. The time burden associated with household energy management is often cited as a major reason educational attainment may suffers, specifically among girls. Reports show that household chores like cooking and collecting fuel wood can significantly reduce the school attendance of young children in developing countries (Rewald, 2017). Burke and Dundas (2015) studied the determinants of solid fuel use from 175 countries between 1990-2010. They found that female labour force participation is associated with a reduction in the domestic use of solid fuels. Dinkelman (2011) found that in South Africa, rural electrification was associated with a 9.5 percent increase in female employment while there was no change in male employment.

Women are generally responsible for cooking and household chores which means that they spend a significant amount of their day indoors. In a study on the effect of fuel wood use on the livelihood of South Africans residing in rural areas Dovie et al. (2004) find that women do most of the cooking in 83% of households. In households that use solid fuels for cooking on inefficient stoves, working indoors means breathing in toxic fumes for hours every day. This suggests that women are more susceptible to the negative health implications of IAP. Indeed several studies on the health effects of IAP in developing countries have found that women in households using solid fuels have worse respiratory health than male residents (Stabridis and van Gameren, 2018; Chen and Modrek, 2018). Stabridis and van Gameren (2018) found that the the use of firewood for cooking increased the prevalence of respiratory problems for women while there was no significant difference for men. Stabridis and van Gameren (2018) then go on to find a negative relationship between negative health outcomes and labour force participation.

Households continue to use solid fuels for cooking despite having access to electricity and knowing that the burning of these fuels has a negative impact on their health. The reason for this is one of poverty and survival. Modern fuels are not accessible to poor households in South Africa and thus the only available option is solid fuels. People have die from IAP exposure, but it is just as true to say that that their deaths are caused by energy poverty. There is a double burden on poor households, not only are they impoverished but because they are impoverished and cannot afford modern fuels, they are prone to various illnesses related to household air quality.

3 Data and Methodology

3.1 Data

This Analysis draws from the General Household Survey (GHS) a cross sectional national representative survey conducted annually by StatsSA (2018). The survey aims to track the success of programs and the state of service delivery. The main areas covered in the survey are health and social development, education, housing, food security, access to services, and agriculture. The GHS uses a two-stage stratified sampling design process: the sampling of primary sampling units (PSUs) with probability proportional to size at the first stage, and sampling of dwelling units at the second stage. The primary stratification is defined by geography type while the secondary stratification is by geography and population attributes prior to the selection of PSUs (StatsSA, 2018). For this analysis we will be using data from this survey in 2018. The use of solid fuel for cooking is most prevalent and has the most severe effect on low-income rural households, therefore; this analysis will only include households residing in rural areas. In 2018 the GHS dataset contains information on $N = 25672$ individuals residing in rural households. The GHS dataset provides household level sampling weights which are used in order to make the sample nationally representative.

The GHS provides a rich dataset containing a range of socio-economic variables at the individual and household level. Each household identifies the main fuel that is used for cooking, lighting, space heating and water heating. A dummy variable was created which indicating whether a household uses solid fuels, wood, coal or animal dung for cooking. Of the 25672 individuals in our sample, $N_t = 13556$ choose to use solid fuels for cooking. This is compared to $N_c = 12116$ individuals who use non-solid cooking fuels.

The GHS contains many health related variables such as whether an individual has suffered from acute respiratory tract infection, TB or severe cough with blood, pneumonia and bronchitis in the last three months as well as if individuals suffer from Asthma. These are all illnesses that have been linked to indoor air pollution. The outcome variables are a set of dummy variables indicating whether an individual has suffered from ARI's, Asthma, Bronchitis, TB, pneumonia in the last three months. A dummy variable indicating whether an individual self-reported a poor health status. This was generated from the self-reported general health variable and is equal to 1 if the individual selected poor health and 0 otherwise. Additionally a dummy variable for general respiratory illness was generated. This variable is equal to 1 in an individual has suffered from any of the above mentioned respiratory illnesses and is equal to 0 otherwise.

3.2 Method: Propensity Score Matching

The aim of this paper is to examine whether there is a potential link between health outcomes and the use of solid cooking fuels among low-income rural households. A major issue with trying to analyse this is that households that use solid fuels are not randomly assigned. Individuals choosing to use modern fuels do so because they are wealthier and are often better informed. Therefore, a comparison between households that use solid fuels and those that do not is confounded by other factors, including poverty and health preferences, which can lead to substantial bias (Duflo et al., 2008). Propensity score matching (PSM) is a method often applied to observational data that intends to mimic the process of random assignment by matching each individual assigned to the treatment with one or more individuals with observably similar characteristics in the control group (Dehejia and Wahba, 2002).

We have restricted the sample to $N = 25672$ individuals residing in rural households. For this analysis the treatment group consists of N_t individuals that reside in households which use solid fuels as their main cooking fuel. This is compared to the control group of N_c individuals residing in households that do not use solid fuels as their main cooking fuel.

To analyse the effect of using solid cooking fuels on health outcomes, we indicate various health outcomes as separate binary variables. The potential outcome variable denoted as $Y_{1i} \in [0, 1]$ is the health outcome of interest conditional on individual i being in the treatment group while $Y_{0i} \in [0, 1]$ is the health outcome conditional on individual i being part of the control group. The health outcomes that will be evaluated are whether an individual has experienced acute respiratory infection (ARI); Tuberculosis (TB) or severe cough with blood; or pneumonia in the last three months. Additionally a dummy variable which indicates self reported poor health is generated to measure perceived general health of an individual.

We would like to know the difference between the health outcomes of those using and not using solid cooking fuels. The treatment effect of using solid fuels for individual i is defined as $\tau_i = Y_{1i} - Y_{0i}$. The fundamental evaluation problem arises because only one potential outcome can be observed for each individual i (Smith and Todd, 2004). As a household's choice to use solid cooking fuels is determined by many factors, the characteristics of those individuals in the treatment and control group are likely to differ substantially. This problem is known as selection bias.

The treatment indicator is a binary variable denoted by T_i, where $T_i = 1$ when individual i belongs to a household that uses solid fuels for cooking and $T_i = 0$ if they do not. Let X_i donate a vector of observed individual and household characteristics used as a conditioning variable. The most common evaluation parameter of interest for observational data is the average treatment effect on the treated. Which is defined as

$$\begin{aligned} \tau_i|_{T_i=1} &= E(\tau_i|X_i, T_i = 1) = E(Y_{1i} - Y_{0i}|X_i, T_i = 1) \\ &= E(Y_{1i}|X_i, T_i = 1) - E(Y_{0i}|X, T_i = 1) \end{aligned} \tag{1}$$

However, the counter-factual $E(Y_{0i}|T_i = 1)$ is not observed and so a suitable alternative must be found. With the observational data being used for this analysis we cannot simply use the mean of the control group $E(Y_{0i}|T_i = 1)$ as a substitute because the factors that determine the choice to use solid fuels would most likely also determine the outcome variable of interest (Caliendo and Kopeinig, 2008). This means that the health outcomes in the treatment and control group would differ even in the absence of treatment which results in selection bias.

Propensity score matching is a method commonly used in the literature to correct for such bias (Dehejia and Wahba, 1999, 2002; Smith and Todd, 2004). Our propensity score, $p(X_i)$, is the probability of an household using solid cooking fuels given the observed characteristics.

$$p(X_i) = Pr(T_i = 1|X_i = x) = E[T_i|X_i = x] \tag{2}$$

We assume that for all X_i there is a positive probability of being assigned to the treatment group, i.e. $0 < p(X_i) < 1$. Matching estimators are justified by the assumption that potential outcomes are independent of treatment assignment conditional on a set of observable characteristics X_i. It has been shown that if the potential outcomes are independent of the treatment conditional on X, they are also independent of the treatment conditional on the propensity scores $p(X_i)$ (Caliendo and Kopeinig, 2008). This is known as the conditional independence assumption (CIA) which can be written as:

$$(Y_{1i}, Y_{0i}) \perp\!\!\!\perp T_i|X_i \Longrightarrow (Y_{1i}, Y_{0i}) \perp\!\!\!\perp T_i|p(X_i) \tag{3}$$

Given the above assumptions hold and that there is overlap between groups the average treatment affect for the treated population is given by:

$$\tau|_{T=1} = E[E(Y_i|T_i = 1, p(X_i)) - E(Y_i|T_i = 0, P(X_i))|T_i = 1] \tag{4}$$

The PSM estimator is the mean difference in outcomes over the common support region weighted by the propensity score distribution of participants (Caliendo and Kopeinig, 2008). The main objective of propensity score matching is to balance the distribution of covariates across the observed treatment and control groups.

3.3 Matching Strategy

One of the more popular matching estimators is the nearest neighbour estimator. With this strategy an individual from the treatment group is matched with the individual from the control group who is the most similar in terms of propensity score (Caliendo and Kopeinig, 2008). As our sample has a large number of observations and the treatment an control groups used for this analysis have sufficient overlap the neighbour neighbour estimator seems the most appropriate. One drawback of the nearest neighbour matching is that information can be lost as it only considers the best matches and disregards matches of poorer quality. Rather than disregarding the information of unmatched individuals the Kernel matching estimator could be used. Kernel matching is a non-parametric matching estimator used to weight averages of individuals in the control group. Only observations that lie outside of the common support region are disregarded when kernel matching is used (Garrido et al., 2014). However, this estimation method can lead to poor matching of individuals. Propensity scores can also be used as weights to balance the distribution between groups. When using inverse-probability treatment weights every individual in the treatment group is weighted by the inverse of the propensity score and those in the control group are weighted by one minus the inverse of the propensity score.

3.4 Balance of Propensity Score and Covariates

Before assessing the quality of the matching procedure it is necessary to check if there is sufficient overlap between the treatment and control group. The psmatch2 command in stata 16 will be used to generate a visual analysis of the density distribution of the propensity scores in both groups (Caliendo and Kopeinig, 2008). Once it has been determined that there is sufficient overlap between the groups the quality of the propensity scores can be assessed. This is done by checking that the matching procedure is able to balance the distribution of the relevant variables in both the control and the treatment group. The basic method for doing this is to compare the situation before and after the matching to check if there is still a difference in the distribution of the variables in the treatment and control groups after conditioning on the propensity scores (Caliendo and Kopeinig, 2008). The standardized bias approach is often used to assess the balance of covariates after matching. This approach uses the standardised bias between the treatment and control group for each covariate group as an indicator of the success of the matching procedure. In most empirical studies a standardised bias below 5% after matching is seen as sufficient (Caliendo and Kopeinig, 2008).

3.5 Variable Selection

The independent variable of interest is exposure to indoor air pollution from the combustion of solid cooking fuels. An accurate measure for the amount of indoor air pollution a household is exposed to would be ideal, however; this measure is impractical for large nationally representative datasets such as the GSH. Therefore this analysis will use an indicator for the households use of solid cooking fuels as a measure of exposure to indoor air pollution which is a measure that has been used extensively in the literature (Qiu et al., 2019; Rahut et al., 2017; Liu et al., 2020; Yu, 2011; Chen and Modrek, 2018).

The outcome variables of interest are various illnesses that have been linked to indoor air pollution from the combustion of solid cooking fuels. Section 2.2 offers a review of the literature around indoor air pollution and health outcomes. From this literature we find that indoor air pollution from solid fuel use has been linked to illnesses such as ARI's, TB, pneumonia, bronchitis, Asthma and self reported poor health. To analyse general respiratory illness variable will be created which will mark whether individuals have suffered from any of the 5 respiratory illnesses analysed in this study.

Based on findings from previous studies various determinants of household fuel choice were selected as control variables. A households choice of cooking fuel is the result of a complex decision making process that is influenced by a wide range of socio-economic factors. Firstly, a set of individual demographic and socio-economic variables are used as covariates, these include age, gender, education and race. Secondly, a set of household level covariates were selected for our analysis. The education level of household members, specifically that of the household head has been found to significantly influence the use of solid fuels within households (Rao and Reddy, 2007). Studies have shown that female households heads generally opt for modern fuels for cooking over solid fuels as women have more control over the resources in these households (Rao and Reddy, 2007). Various studies have found that increasing household size is correlated with an increase in the probability of a household using solid fuels for cooking (Alem et al., 2016). There is evidence which suggests employment is a significant determinant of solid fuel use, therefore, the proportion of economically active[2] employed household members is used as a measure of employment for the household. It would also be useful to control for the presence of both indoor and outdoor pollution which would be correlated to both the independent and outcome variables. Per capita household income is included as it has consistently been found to be one of the most significant determinants of solid fuel use and would also influence the health related outcome variables. Access to modern energy is another factor that will influence a households choice to use solid fuels. Therefore; whether the household has access to electricity will be included as covariate.

3.6 Descriptive Statistics

For propensity score methods to be valid the outcome variable must be independent of the treatment variable given the propensity score $p(X_i)$. This means that the variables chosen to compare individuals must determine both the respondents decision to use solid fuels and the potential health outcomes of interest.

[2]Economically active members of the household are those working age adults who are either employed or actively seeking employment

Table 1: Sample means of characteristics for treatment and control

Variables	Treatment Mean (1)	Control Mean (2)	Difference (2)-(1) Mean (3)	t-statistic (4)
ARI	0.066	0.067	0.001	0.274
	(0.004)	(0.004)		
Asthma	0.010	0.009	-0.001	-0.71
	(0.001)	(0.001)		
Bronchitis	0.001	0.001	0.001	1.339
	(0.000)	(0.000)		
TB	0.005	0.004	-0.001	-0.641
	(0.001)	(0.001)		
Pneumonia	0.000	0.000	0.000	1.033
	(0.000)	(0.000)		
Respiratory illness	0.078	0.079	0.001	0.174
	(0.004)	(0.004)		
Bad health	0.027	0.015	-0.012***	-6.343
	(0.003)	(0.001)		
Age	25.465	26.692	1.041***	4.023
	(0.195)	(0.217)		
Female	0.540	0.515	-0.028***	-4.656
	(0.004)	(0.005)		
Education	5.616	6.902	1.445***	25.914
	(0.052)	(0.060)		
African	0.991	0.949	-0.035***	-18.879
	(0.003)	(0.009)		
Coloured	0.008	0.032	0.016***	11.290
	(0.003)	(0.008)		
Indian	0.000	0.001	0.001*	2.475
	(0.000)	(0.000)		
White	0.001	0.018	0.018***	15.358
	(0.000)	(0.003)		
Female Head	0.579	0.489	-0.085***	-14.288
	(0.013)	(0.013)		
Education Head	5.418	8.161	2.764***	52.403
	(0.118)	(0.118)		
Mean HH Employment	0.139	0.269	0.116***	38.648
	(0.005)	(0.007)		
HH Size	6.995	5.359	-1.263***	-34.465
	(0.151)	(0.094)		
pollution	0.204	0.209	0.013**	2.787
	(0.017)	(0.016)		
Per Capita Income (HH)	812.678	2006.846	1100.080***	37.990
	(21.966)	(67.680)		
HH Electricity Access	0.902	0.977	0.069***	24.502
	(0.010)	(0.004)		
No. of observations	13556.000	12116.000		

Note: $^{***}p < 0.01$ $^{**}p < 0.05$ $^{*}p < 0.10$.

Table 2 reports the pre-matching sample mean for both the outcome and explanatory variables. Column 1 report the means for individuals living in rural households that use solid cooking fuels, the treatment group, and compares this to the sample means of the control group, column 2. A t-test was performed to test whether the difference in means between the two groups was statistically significant and the difference in means and the t-statistic are reported in column 3 and 4 respectively. We can see that the only outcome variable that is significantly different between the treatment and control group . There is also a slightly higher proportion of people reporting to have bad health in the treatment group, significant at the 1% level.

We can see that the treatment group is younger, has a lower education level and consist of more African individuals. There are proportionally more female headed households and the household heads within the treatment group are older and less educated. The proportion of economically active individuals that are employed is lower for the treatment group and these households are larger in general. Interestingly there is slightly more indoor and outdoor pollution reported in the control group. The treatment group have a per capita income that is less than half that of the control group. The percentage of households that have access to electricity is significantly lower in the treatment group compared to the control. We can see that the sample means of the characteristics of interest differ quite significantly between groups, suggesting that there are different distributions of covariates between the treatment and control. This reinforces the need for propensity score matching as a tool to correct for the imbalances in the covariates.

4 Estimation Results

4.1 Preliminary Estimation

Table 2 presents the estimates of a probit model on the selected determinants of an individuals choice to use solid cooking fuels. These results show that all estimated coefficients are statistically different from zero except for individual gender or race variables. We can see from the probit estimates that socio-economic variables are important determinants of a household use of solid fuels. An increase in education, employed household members and household per capita income and having access to electricity decreases the probability of using solid cooking fuels. Household size and living in a female headed household increases the probability of using solid cooking fuels.

Table 2: Determinants of household use of solid cooking fuels

Variables	Coefficients	Robust S.E.
Age	0.0011***	0.000
Female	-0.0051	0.017
Education	-0.0081***	0.002
African	0.0270	0.433
Coloured	-0.6210	0.464
White	-0.5990	0.464
Female Head	0.0465***	0.018
Head Education	-0.061**	0.002
Mean Employed	-0.4005***	0.044
HH Size	0.0448***	0.003
Pollution	-0.1275***	0.021
PC HH Income	-0.000102***	6.63e-06
Electricity Access	-0.9603***	0.041
Constant	1.3287**	0.437
Pseudo R2	0.1249	
Observations	25672	

Note: $^{***}p < 0.01$ $^{**}p < 0.05$ $^{*}p < 0.10$.

Figure 1 presents an overlap plot of the density of the propensity scores for the treatment and control from the nearest neighbour matching method. We see that there is sufficient overlap and the densities do not mass significantly around 0 or 1, therefore the propensity scores meet the overlap or common support assumption (Busso et al., 2014).

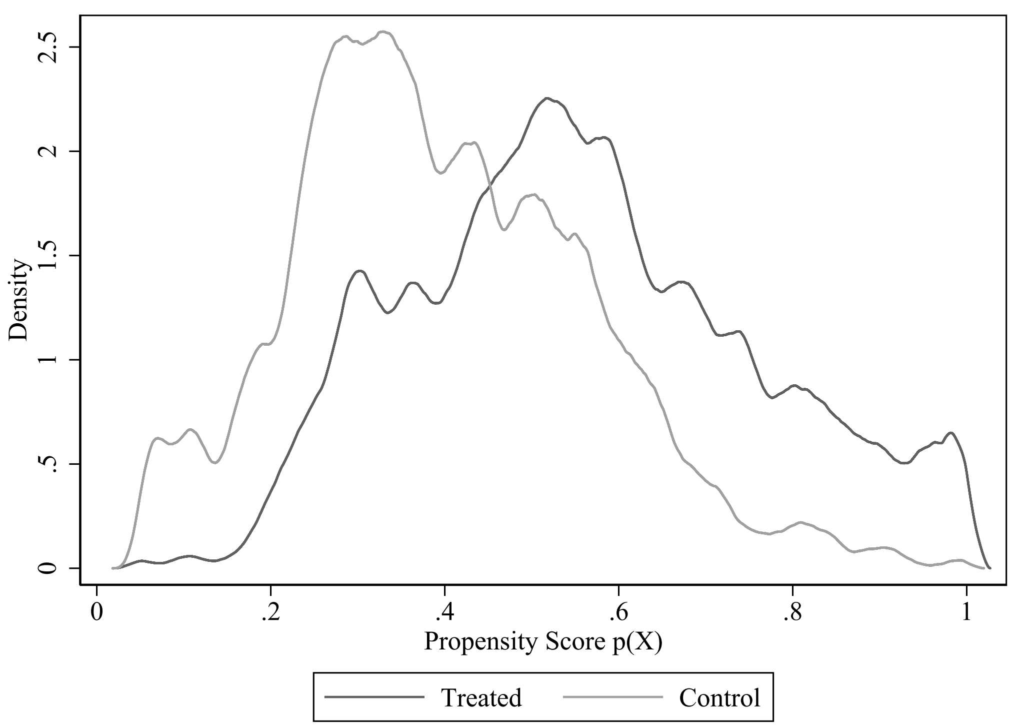

Figure 2: Density of propensity scores for treatment and control group

To be efficient, propensity score matching must balance the individual covariates across treatment and control groups. Table 3 presents a covariate balancing test which represents a comparison of the means of the covariates used to match the treatment and control groups as well as the percentage bias before and after nearest neighbour matching. Overall it seems like the covariates are sufficiently matched. Column (1) and (2) represent the means of the unmatched treatment and control groups respectively. Column (3) and (4) represent the mean of the matched treatment and control group. Column (5) and (6) represent the standardised bias between the means of the treatment and control groups in the matched and unmatched sample. Overall the sample means between the treatment and control groups for the matched sample have largely equalised. It is worth noting that Household size, Exposure to pollution, per capita household income and access to electricity are still significantly different even after matching. It is therefore clear that this is an imperfect match, however, these differences in means seem to be acceptable given that the standardized bias after matching is below 5% for the four covariants in question. We can see a considerable reduction in the bias for every covariate and therefore can infer that from this that the matching is adequate. Panel B of Table two reports the overall balancing properties. Column (1) shows the Psuedo R-squared for the matched and unmatched samples, we can see that the Pseudo R-squared is very low after matching. Column (2) represents Likelihood ratio test of the matched. Column (3) presents the mean bias which was reduced significantly from 26.5% to 1.5% after matching.

Table 3: Covariate balancing tests from nearest-neighbour matching methods

Panel A: test of balancing property for explanitory variables

	Unmatched		Matched			
	Treatment Mean	Control Mean	Treatment Mean	Control Mean	%bias unmatched	%bias match
Variables	(1)	(2)	(3)	(4)	(5)	(6)
Age	26.99	28.031	27.069	27.285	-4.9***	-1.0
Female	.550	.522	.553	.561	5.6***	-1.7
Education	5.483	6.928	5.448	5.37	-31.5***	1.7**
African	.992	.957	.993	.993	22.5***	0.0
Coloured	.006	.022	.006	.006	-13.5***	-0.2
Indian	.000	.001	.000	.000	-2.9**	0.3
White	.001	.02	.001	.000	-18.2***	0.4
Female Head	.602	.517	.606	.659	17.2***	1.3
Head Education	5.28	8.035	5.238	5.201	-63.9***	0.9
Mean Employed	.131	.247	.133	.136	-46.3***	-1.5
Household Size	6.235	4.967	6.289	6.174	41.7***	3.8**
Pollution	.188	.201	.190	.198	-3.4***	-2.2*
PC Income	839.05	1939.1	90757	896.71	-45.8***	-2.6**
Electricity Access	.908	.977	.908	.898	-29.9***	3.9**

Panel B: Overall test of balancing property

Sample	Pseudo R2	LR chi2	Mean bias	Median bias
Unmatched	0.125	4435.53***	26.5	22.5
Matched	0.001	55.18***	1.5	1.7

Note: ***$p < 0.01$ **$p < 0.05$ *$p < 0.10$.

4.2 Aggregate Analysis

Table 4 represents the estimation results for the effect of using solid cooking fuels on various health outcome. For robustness three PSM estimators were used, nearest neighbour matching methods, kernel density matching methods, and inverse-probability treatment weights. The results from the three matching strategies are only slightly different which suggests that type of matching estimator used for this analysis is not necessarily important, therefore; we will use the nearest neighbour matching method to analyse our results going forward. When looking at general health, individuals living in a rural household that uses solid fuels for cooking are 0.7% more likely to self-report that there general health status is poor, at the 10% level of significance. Our results show that the respiratory illnesses that had ATET which were significantly different from zero were ARI's and general respiratory illness. Individuals living in rural areas are 1,6% and 1.8% more likely to suffer from ARI's and respiratory illness respectively if they use solid fuels for cooking, this is at the 1% level of significance. This provides some evidence that the use of solid cooking fuels has an adverse effect on respiratory health. Our findings are in line with the literature as they show some correlation between poor health and respiratory illness in households that are exposed to IAP from burning solid cooking fuels.

Table 4: Impact of the use of solid fuels on the health of households using solid fuels

	Nearest Neighbor Matching	Weighted Least Squares	Kernel Matching
Poor Health	0,007**	0,008***	0,012***
	(0,003)	(0,002)	(0,002)
ARI	0,016***	0,009**	0,007**
	(0,004)	(0,004)	(0,003)
Asthma	0,002	0,002	0,001
	(0,002)	(0,001)	(0,001)
Bronchitis	0,000	0,000	-0,000
	(0,000)	(0,000)	(0,000)
Tuberculosis	-0,001	0,000	0,001
	(0,002)	(0,001)	(0,000)
Pneumonia	0,000	0,000	0,000
	(0,000)	(0,000)	(0,000)
Respiratory Illness	0,018***	0,010***	0,08**
	(0,005)	(0,004)	(0,003)
No. observations	25672	25672	25672

Note: ***$p < 0.01$ **$p < 0.05$ *$p < 0.10$. Standard errors in brackets

4.3 Subgroup Analysis

Our main analysis shows that the use of solid fuels has an effect on the respiratory health outcomes such as ARI's and being classified as having a respiratory illness. There is some evidence to suggest that using solid fuel significantly effects health outcomes of rural households in our main sample. Multiple studies have, however, cited that the health implications of solid fuel use are significantly more severe for different subgroups of the population. It has been consistently cited that women, young children and the elderly are the most vulnerable to the effects of indoor air pollution and therefore experience worse health outcomes. Qiu et al. (2019) finds that indoor air pollution tends to be more sever in specific regions or rural China and that women experience worse health outcomes compared to men when exposed to indoor air pollution. To provide a more comprehensive analysis, it is important to examine the impact of domestic solid fuel use for different gender and age groups.

Due to gender roles in the household rural women are generally in charge of cooking and household chore. They are therefore exposed to IAP from cooking with solid fuels for extended periods of time. We would expect that this would result in more adverse health effects for women when compared to men when using solid cooking fuels. Table 5 presents the average treatment effect using solid cooking fuels by gender. Column (2) and (3) show the average treatment effect for women and men respectively. The results provide some evidence of the gendered effect of solid fuel use on health outcomes. When looking at self reported poor health we can see that women in households that use solid cooking fuels are 1% more likely to report a poor health status, at the 5% level of significance. No significant difference was found for men. When looking at respiratory health outcomes we find that women in rural households that use solid cooking are 0.1% more likely to suffer from Bronchitis. We also find that women residing in households that use solid cooking fuels are 0.8% more likely to report bad general health at the 1% level of significance. No significant result was found among male respondent for any of the health outcomes measured.

Most of the research into the adverse health effects of IAP from the combustion of solid fuels in South Africa has looked into its effects on the repository health of children. Children under 5 are particularly vulnerable to contracting ARI's from indoor are pollution as their lungs are not fully developed. Various international studies in developing countries around Asia have found that the elderly are more susceptible to respirator illnesses as a result of IAP from the burning of solid fuels indoors (Qiu et al., 2019; Liu et al., 2020). Liu et al. (2020) found that individuals over the age of 60 that reside in households that use solid cooking fuels were significantly more likely to suffer the adverse health effects compared to those under 60. Qiu et al. (2019) found that elderly individuals using solid fuels were more likely to be diagnosed with respiratory diseases. Based on the the findings of previous studies we separate our sample into 4 age subgroups, infants (Age<5), children (Age<14), adults (16<Age<60), elderly (Age>60). The results for the average treatment effect using the nearest neighbour matching method by age group are presented in table 6. The results show that infants residing in households that use solid cooking fuels are 0.4% more likely to have a poor health status. No significant results for the effect of solid cooking fuels on respiratory illness for infants and children were found. This contradicts findings in the literature that children and infants are worse affected by indoor air pollution compared to other age groups. The results show that the elderly are 3.1% more likely to report poor health when living in households that use solid cooking fuels, at the 5% level of significance. The elderly are also 0.3% less likely to suffer from Asthma when residing in rural households that use solid cooking fuels, but this is only significant at the 10% level of significance. Adults were found to be 0.1%

more likely to suffer from from bronchitis and 1.5% more likely to suffer from one of the respiratory illnesses mentioned in this study when they reside in households that use solid cooking fuels. Both of these were found to be significant at the 10% level of significance.

Table 5: Impact of using solid fuels on health outcomes by gender

		Gender	
	Overall	Female	Male
	(1)	(2)	(3)
Poor Health	0,007**	0,010**	-0,006
	(0.003)	(0.004)	(0.005)
ARI	0,015**	0,011	0.005
	(0.005)	(0.008)	(0.09)
Asthma	0,002	-0,001	0,003
	(0,002)	(0,003)	(0,002)
Bronchitis	0,000	0.001**	-0,002
	(0,001)	(0,000)	(0,002)
TB	0,001	0,001	0,000
	(0,001)	(0.002)	(0.002)
Pneumonia	0,000	-0,000	0,000
	(0,000)	(0.000)	(0.000)
Respiratory Illness	0,017***	0,010	0,005
	(0.005)	(0.008)	(0.007)
No of observations	25672	13875	11797

Note: ***$p < 0.01$ **$p < 0.05$ *$p < 0.10$. Standard errors in brackets

Table 6: Impact of using solid fuels on health outcomes by age group

		Age Group			
	Overall	Infant	Child	Adult	Elderly
	(1)	(2)	(3)	(4)	(5)
Poor Health	0,007**	0,004***	0,003	0,007	0,031**
	(0.003)	(0.002)	(0.002)	(0.007)	(0.016)
ARI	0,015***	0,011	0,007	0,010	0,016
	(0.005)	(0.011)	(0.010)	(0.008)	(0.017)
Asthma	0,0002	0.000	0,000	0,004	-0,003*
	(0,002)	(0,002)	(0,001)	(0,002)	(0,012)
Bronchitis	0,000	0,000	0,000	0,001*	-0,005
	(0,001)	(0,000)	(0,000)	(0,000)	(0,001)
TB	0,000	-0,003	0,001	0,001	0,001
	(0,001)	(0,002)	(0,002)	(0,002)	(0,007)
Pnemonia	0,000	-0,000	-0,000	-0,000	0,001
	(0,000)	(0.000)	(0.000)	0.000)	(0.001)
Respiratory Illness	0,017***	0,007	0,007	0,015*	0,008
	(0.005)	(0.011)	(0.010)	(0.008)	(0.02)
No of observations	25672	6226	9426	10945	2781

Note: ***$p < 0.01$ **$p < 0.05$ *$p < 0.10$. Standard errors in brackets

4.4 Discussion

Our results on various health outcomes related to IAP from the use of solid cooking fuels somewhat in line with findings of previous studies, such as Rahut et al. (2017); Qiu et al. (2019); Liu et al. (2020); Chen and Modrek (2018); Albers et al. (2015). Although our results are modest we find that the use of solid cooking fuel is correlated with an increase in the likelihood of suffering from an ARI or one of the respiratory illnesses chosen for this analysis. It has been consistently sighted in the literature that women and children are the worst affected by IAP from the combustion of solid cooking fuels. We find that women residing in household that use solid fuels are more likely to report a poor health status and slightly more likely to suffer from bronchitis. None of the health outcomes analysed were found to be significantly impacted by the use of solid fuels among men. This provides some evidence that women residing in households that use solid cooking fuels are more likely to suffer from adverse health outcomes although this evidence is not substantial. Despite numerous studies finding that young children are worse affected by the use of solid cooking fuels we find little evidence to support this in our analysis. In accordance with the findings of Qiu et al. (2019) and Liu et al. (2020) we find that elderly individuals residing in households that use solid fuels are significantly more likely to report poor health which suggests the general health of elderly people suffers relatively more than other age groups from the use of solid cooking fuels.

5 Conclusion

There is a large body of evidence which supports the claim that the inefficient combustion of solid fuels within a household has adverse effects on the health and well-being of residents (Rahut et al., 2017; Shezi and Wright, 2018; Vegter, 2016; WHO, 2016; Qiu et al., 2019). A limited number of studies conducted in South Africa provide evidence that indoor air pollution significantly affects the respiratory health and general well-being of rural residents. This study contributed to the literature on the health effects of IAP from the use of solid fuels in South Africa, using the nationally representative General Household Survey (GHS, 2018).

In line with the literature, we find some evidence to suggest that using solid cooking fuels has adverse effects on respiratory health outcome of individuals. We see a slight increase in the incidence of ARI's and general respiratory illness. However, this result is only significant for the entire population of rural households. When looking specifically and age and gender subgroups we do not find evidence of significant increases in the incidence of respiratory illnesses in households that use solid cooking fuels. This contradicts various studies which have consistently found respiratory health of women and young children is worse affected by the use of solid cooking fuels. There seems to be a slightly higher incidence of self-reported poor health in households that use solid fuels for cooking, however, this is not enough evidence to show that cooking with solid fuels is correlated with adverse health outcomes.

Although the GHS data set allows for the an analysis of the health outcomes from indoor air pollution caused by the combustion of solid cooking fuels on a nationally representative sample, using this data comes with its limitations. A major limitation of using this survey data is the lack of information needed to effectively measure the amount of indoor air pollution individuals are exposed to by using solid cooking fuels. The GHS has no information on whether individuals cooked the majority of their meals indoors, if they had access to efficient biomass stoves, the level of ventilation in the household, or the length of time that individuals were exposed to the smoke from burning solid fuels. Our measure for indoor air pollution was simply the use of solid fuels for cooking. Although various studies have used this as a proxy for IAP in the past there will be significant variation in the level of indoor air pollution that households which use solid cooking fuels would be exposed to. A more precise measure for the level of IAP exposure is needed for an accurate analysis of its affect on health outcomes. There are many confounding variables that are omitted from the GHS that could lead to substantial bias. Although some bias can be corrected for with propensity score matching, the matching is not perfect and unmeasured important covariates can significantly bias the treatment effect estimates (Garrido et al., 2014). Propensity score matching only controls for bias from the observed difference between the treatment and control groups. This is a major trade-off that is made in order to use large nationally representative surveys and it is likely that our results are biased. Another limitation of this study is that from the data, we are only able to identify a correlation between cooking with solid fuels and adverse health outcomes this would not provide enough evidence to say that there is a causal link between the use of solid cooking fuels and health outcomes.

Further research is needed to understand the magnitude of the use of dirty fuels on the health and well-being of South Africans, specifically women and children. If possible larger studies with a more accurate measure for IAP should be obtained. Further research could look into how solid fuel use affects the economic outcomes of women and girls. At large it is difficult to accurately measure the impact of indoor air pollution on health outcomes using nationally representative studies. A suggestion would be to perform a study that focuses on the priority areas in South Africa which have recorded the highest levels of indoor and outdoor air pollution.

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